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Note on Variations in the "Quasi-Biennial" Oscillation

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ABSTRACT Significant temporal variations in the "quasi-biennial" oscillation (QBO) of the equatorial stratosphere raise questions concerning relationships between the various characteristics of the oscillation. A comparison of observations made before 1962 with those made after 1962 suggests the following relationships: $\beta \approx P_U/4$ in the 10- to 30-mb layer; $P_U/8 \leq \beta \leq P_U/4$ in the 30- to 50-mb layer; and $c_U P_U \approx$ constant from 10 to 50 mb (where β is the phase difference between the zonal wind-QBO and temperature-QBO, P_U is the period of the zonal wind-QBO, and c_U is the speed of vertical propagation of the zonal wind-QBO).

1. INTRODUCTION

Following the suggestion by Palmer (1954) and Lettau (1956) that the semipermanent features of the equatorial circulation might be in geostrophic balance, Reed (1962, 1964) compared the so-called 26-mo temperature oscillation with the corresponding oscillation of the zonal wind. By calculating such characteristics of the temperature wave as would be required by the thermal wind relationship to conform to the observed winds and by comparing these with the observed temperatures, he showed, on the basis of the data then available, that the 26-mo oscillation was in geostrophic equilibrium.

It had become increasingly apparent, by the time of Reed's study, that the period of this phenomenon is quite variable in time and space while averaging out to about 26 mo. One began to speak, more appropriately, of the "quasi-biennial" oscillation (QBO). It now appears to be as much triennial as biennial, and perhaps the time has come to give it still another name. Moreover, around 1962, an increase in the phase difference between the temperature oscillations and wind oscillations appeared at 10 mb while at lower levels it remained approximately constant (McInturff et al. 1971, fig. 4). At the same time, the regularity in the ozone oscillation disappeared. Some authors have consequently spoken of a breakdown in the QBO (e.g., Sparrow 1971).

In this note, we examine data compiled since 1962 in an effort to quantify further the observed variations in the QBO. We make a further study of temperatures and zonal winds for Canton Island, Ascension Island, and Balboa, C.Z., including consideration of the 10-mb level along with lower levels. Statistics are derived for the period of record prior to 1962 and for that subsequent to 1962. Fixing the time of the breakdown in this manner is rather arbitrary, but some justification has been given by McInturff et al. (1971).

2. ANALYSIS OF DATA

The record used for Canton Island (3°S, 172°W) at 30 and 50 mb extends from 1954 through 1966; at 10 mb, it extends only from 1962 through 1966. All observations ceased at Canton in 1967. The record for Ascension Island (8°S, 15°W) at all levels extends from 1958 through 1969, while for Balboa (9°N, 80°W) it extends from 1951 through 1969 at 50 and 30 mb, from 1958 through 1969 at 10 mb.

Monthly mean temperatures and winds at 50, 30, and 10 mb for the three stations were the basic data used. These were smoothed by taking 12-mo running means, thus effectively removing the annual cycle. A cross-covariance program was employed to calculate (1) autocorrelation coefficients of temperatures and of zonal winds at various time lags at 1-mo intervals for 0–36 or 0–24 mo, depending on the length of record, for all levels, giving the periods of the wind and temperature oscillations (P_U and P_T, respectively) and (2) cross-correlation coefficients of temperature and zonal winds, giving the phase differences, β, between the two oscillations. Moreover, by taking interlevel correlations, the rates of vertical propagation of the wind oscillation and of the temperature oscillation (c_U and c_T, respectively) were computed.

The results are shown in table 1. Especially noteworthy is the consistency among values of P_U. The period of the wind oscillation is revealed as significantly greater after 1962 than before 1962 at all stations and at all levels. The behavior of the temperature oscillation is significantly different: the lengthening of the period is about the same at 50 mb as for the wind oscillation, but this lengthening amounts to only about half of that for the wind oscillation at 10 mb. It is not surprising, then, to find important differences in phase at 10 mb [β (10)] between the post-1962 and the pre-1962 periods.

The rates of downward propagation, $|c_U|$ and $|c_T|$, assumed by Reed (1964) to be constant, are shown to

TABLE 1.—*Values at 10, 30, and 50 mb of* P_U *(period of wind-QBO),* P_T *(period of temperature-QBO), and* β *(phase difference between temperature-QBO and wind-QBO); also of* c_U *(speed of vertical propagation of wind-QBO) and* c_T *(speed of vertical propagation of temperature-QBO). Units of* P_U, P_T, and β *are mo; units of* c_U *and* c_T *are km/mo.*

	Canton		Ascension		Balboa		
	Pre-62	Post-62	Pre-62	Post-62	Pre-62* (1952–62)	Pre-62* (1958–62)	Post-62
$P_U(10)$	—	34	22	34	—	21	34
$P_U(30)$	25	30	22	32	26	21	33
$P_U(50)$	25	32	22	33	26	22	34
$P_T(10)$	—	27	26	32	—	24	31
$P_T(30)$	25	35	22	30	26	24	33
$P_T(50)$	24	36	26	36	25	25	36
$\beta(10)$	—	9	3	9	—	4	10
$\beta(30)$	5	7	5	6	5	4	4
$\beta(50)$	3	4	4	7	5	6	4
$c_U(10-30)$	—	−0.9	−1.3	−0.9	—	−1.3	−0.9
$c_U(30-50)$	−1.0	−0.8	−1.3	−0.8	−1.0	−1.3	−0.8
$c_T(10-30)$	—	−0.7	−1.6	−0.7	—	−1.3	−0.7
$c_T(30-50)$	−0.8	−0.7	−1.3	−1.3	−1.3	−1.3	−1.0

* The pre-1962 period for Balboa is divided into two parts because the record for 30 mb and 50 mb begins in 1951 while that for 10 mb begins only in 1958. Although the 10-mb period of record for Canton is also shorter than that of other levels, it conveniently begins at the time of the QBO breakdown in 1962. See the account given in section 2.

decrease in all but one case from more than 1 km/mo to less than 1 km/mo between the pre-1962 period and the post-1962 period. It should be noted that c_U and P_U are approximately inversely proportional to one another, that is, $c_U P_U \approx$ constant. For the following development, it seems legitimate to treat c_U and c_T as constants for thin layers and over the separate periods under consideration.

3. MODEL CONSIDERATIONS

With the limited amount of data used in the present study, no attempt has been made to verify geostrophy on a scale such as Reed attempted in 1964. Following Reed, we make use of the formula

$$\beta=\frac{P_U}{2\pi}\arctan\left(-\frac{B}{A}\right) \tag{1}$$

where, under the assumption of geostrophy,

$$A=\int_{\cos\phi_1}^{\cos\phi_2}\frac{\partial U}{\partial z}\,d(\cos\phi)$$

and

$$B=\frac{2\pi}{P_U c_U}\int_{\cos\phi_1}^{\cos\phi_2}U d(\cos\phi).$$

U is the amplitude of the zonal wind wave, $\partial U/\partial z$ is the rate of change with height of this amplitude, ϕ is latitude, and the other symbols have their usual meanings.

Taking $\phi_2=15°$ (north or south latitude), where the temperature oscillation effectively goes to zero (Angell and Korshover 1970) and ϕ_1 is the latitude of Canton, Balboa, or Ascension, we obtain

$$\beta=\frac{P_U}{2\pi}\arctan\left(\frac{-2\pi}{P_U c_U}\frac{\overline{U}}{\overline{\partial U/\partial z}}\right) \tag{2}$$

where the overbar denotes a mean taken over a latitude band (in this case, 3°–15°). For example, between Canton and 15° N in the 10- to 30-mb layer, we have $\overline{U}=24$ kt and $\overline{\partial U/\partial z}=0.2$ kt/km, so that $\overline{U}\,(\overline{\partial U/\partial z})^{-1}=120$ km. Thus,

$$\beta\approx\frac{P_U}{2\pi}\arctan 26$$

and

$$\beta\approx\frac{P_U}{2\pi}\cdot\frac{\pi}{2}=\frac{P_U}{4}.$$

In general, since $\overline{U}\,(\overline{\partial U/\partial z})^{-1}$ is so large, arctan $(-B/A)$ approaches $\pi/2$ and β can be approximated between 10 and 30 mb by $P_U/4$. Below the 10-to 30-mb layer, $\overline{\partial U/\partial z}$ is so large that the approximation, $\beta\approx P_U/4$, cannot be used. However, calculations of β from eq (2) show that in all cases considered

$$\frac{P_U}{8}\leq\beta\leq\frac{P_U}{4}. \tag{3}$$

A comparison of observed values of β with those values deduced from eq (2)—values obtained under the assumption of geostrophy—is given in table 2 for the 10- to 30-mb layer and for the 30- to 50-mb layer. Agreement is generally good in view of the several assumptions made in the model. The only exception is Balboa, for the 30- to 50-mb layer in the post-1962 period; the reason for this is not presently known to the authors.

TABLE 2.—*Observed values of* β *(in mo) and those values calculated on the assumption of geostrophy for two stratospheric layers*

	Canton		Ascension		Balboa		
	Pre-62	Post-62	Pre-62	Post-62	Pre-62 (1952–62)	Pre-62 (1958–62)	Post-62
10–30 mb							
β observed	—	8	4	7	—	4	7
β calculated	—	8	5	8	—	5	8
30–50 mb							
β observed	4	6	5	7	5	5	4
β calculated	5	7	4	7	6	4	7

4. CONCLUSIONS

Our results suggest (on the basis of the assumptions that enter into the model) that the QBO has remained in roughly geostrophic equilibrium since it was first observed. In fact, the increase in observed β at 10 mb appears to result from an adjustment to geostrophic equilibrium.

Geostrophy requires that β be related to P_U; the relationship is especially simple in the 10- to 30-mb layer, where $\overline{\partial U/\partial z}$ becomes very small, and, consequently, $\beta\approx P_U/4$. This relationship, as well as the inequality $P_U/8\leq\beta\leq P_U/4$ for the 30- to 50-mb layer, appears to be well confirmed by observation.

Since the eruption of Mt. Agung in 1963 is known to have had effects on the stratosphere (e.g., Newell 1970, McInturff et al. 1971), the question arises as to whether this eruption, almost coinciding as it did with the breakdown of the QBO, could have had some influence on this breakdown. It seems that the type of argument advanced by Wallace (1967) can be used against this conjecture.

Wallace showed that the kinetic energy required by the QBO as a whole is much greater than that required by the temperature oscillation alone. With geostrophy being maintained in the QBO, the temperature and wind fields must be related; and, although no calculations have been made, it appears most unlikely that the relatively small variations in temperature attributable to the Bali eruption can account for the very large fluctuations in kinetic energy required by the phase shifts occurring about 1962.

Of additional interest is the relationship of inverse proportionality between c_U and P_U; that is, $c_U P_U \approx$ constant. This is a surprising result that warrants further investigation: Why should long waves propagate downward more slowly than short waves?

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REFERENCES

Angell, James K., and Korshover, Julius, "Quasi-Biennial, Annual and Semiannual Zonal Wind and Temperature Harmonic Amplitudes and Phases in the Stratosphere and Low Mesosphere of the Northern Hemisphere," *Journal of Geophysical Research, Oceans and Atmospheres,* Vol. 75, No. 3, Jan. 20, **1970**, pp. 543–550.

Lettau, Heinz H., "Theoretical Notes on the Dynamics of the Equatorial Atmosphere," *Beiträge zur Physik der Atmosphäre,* Vol. 29, No. 2, Vieweg & Sohn, Frankfurt a.M., Germany, Mar. **1956**, pp. 107–122.

McInturff, Raymond M., Miller, Alvin J., Angell, James K., and Korshover, Julius, "Possible effects on the Stratosphere of the 1963 Mt. Agung Volcanic Eruption," *Journal of the Atmospheric Sciences,* Vol. 28, No. 7, Oct. **1971**, pp. 1304–1307.

Newell, Reginald E., "Stratospheric Temperature Change from the Mt. Agung Volcanic Eruption of 1963," *Journal of the Atmospheric Sciences,* Vol. 27, No. 6, Sept. **1970**, pp. 977–978.

Palmer, Clarence Edgar, "The General Circulation Between 200 Mb and 10 Mb Over the Equatorial Pacific," *Weather,* Vol. 9, No. 11, Royal Meteorological Society, London, England, Nov. **1954**, pp. 341–349.

Reed, Richard J., "Evidence of Geostrophic Motion in the Equatorial Stratosphere," *Quarterly Journal of the Royal Meteorological Society,* Vol. 88, No. 377, London, England, July **1962**, pp. 324–327.

Reed, Richard J., "A Tentative Model of the 26-Month oscillation in Tropical Latitudes," *Quarterly Journal of the Royal Meteorological Society,* Vol. 90, No. 386, London, England, Oct. **1964**, pp. 441–466.

Sparrow, J. G., "Stratospheric Properties and Bali Dust," *Nature,* Vol. 229, No. 5280, MacMillan Journals, Ltd., London, England, Jan. 8, **1971**, p. 107.

Wallace, John M., "A Note on the Role of Radiation in the Biennial Oscillation," *Journal of the Atmospheric Sciences,* Vol. 24, No. 5, Sept. **1967**, pp. 598–599.

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